

*AREVA Report No. 51-9177315-001, Brunswick Unit 1 Cycle 19  
SLMCPR Analysis With SAFLIM3D Methodology –  
Operability Assessment (Nonproprietary Version)*



# AREVA NP Inc.

## ENGINEERING INFORMATION RECORD

Document No: 51 - 9177315 - 001

**Brunswick Unit 1 Cycle 19 SLMCPR Analysis  
With SAFLIM3D Methodology – Operability  
Assessment (Nonproprietary Version)**



Brunswick Unit 1 Cycle 19 SLMCPR Analysis With SAFLIM3D  
Methodology – Operability Assessment (Nonproprietary Version)

Safety Related?  YES  NO

Does this document contain assumptions requiring verification?  YES  NO

Does this document contain Customer Required Format?  YES  NO

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**Record of Revision**

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial issue of document.
001	Page 5 Page 10, Figure 3	Updated Reference 7 to Revision 1. Updated rated power distribution.

Changes are further identified by a vertical bar in the right-hand margin.

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## 1.0 Purpose

Reference 1 presents an AREVA methodology for determining the safety limit minimum critical power ratio (SLMCPR) that was recently approved by the NRC. The methodology is an update or extension of the previously approved methodology presented in Reference 2. The SLMCPR methodology was updated to incorporate full implementation of the ACE critical power correlation (References 3 and 4), a realistic fuel channel bow model (Reference 5), and expanded coupling with the MICROBURN-B2 core simulator (Reference 6). More detailed descriptions of these improvements are discussed in Reference 1.

Reference 7 presents results of the Brunswick Unit 1 Cycle 19 (BRK1-19) SLMCPR analysis using the currently approved Reference 4 ACE/ATRIUM™ 10XM\* critical power correlation. As discussed in Reference 8, a concern was identified in the calculation of the K-factor within the approved ACE/ATRIUM 10XM correlation. The K-factor methodology was modified in response to the deficiencies found in the axial averaging process. An updated correlation for use in the Brunswick SLMCPR operability assessment calculations with ATRIUM 10XM fuel is described in Reference 8.

The purpose of this report is to present results of an operability assessment for the BRK1-19 SLMCPR calculations presented in Reference 7 using the updated critical power correlation described in Reference 8 for the ATRIUM 10XM fuel. The results of this analyses support a change in the list of approved methodologies in the Technical Specifications and also a change in the Technical Specification SLMCPR values for two-loop operation (TLO) and single-loop operation (SLO).

## 2.0 Methodology

The analysis presented in this document used the methodology presented in Reference 1 and the operability assessment critical power correlation presented in Reference 8 for the ATRIUM 10XM fuel. The SLMCPR is defined as the minimum value of the critical power ratio which ensures that at least 99.9% of the fuel rods in the core are expected to avoid boiling transition during normal operation or an anticipated operational occurrence (AOO). The SLMCPR is determined using a statistical analysis that employs a Monte Carlo process that perturbs key input parameters used in the calculation of MCPR. The set of uncertainties used in the statistical analysis include both fuel-related and plant-related uncertainties.

The SLMCPR analysis is performed with a power distribution that conservatively represents expected reactor operating states that could both exist at the operating limit MCPR (OLMCPR) and produce a MCPR equal to the SLMCPR during an AOO. [

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In the AREVA methodology, the effects of channel bow on the critical power performance are accounted for in the SLMCPR analysis. Reference 1 discusses the application of a realistic channel bow model.

### 3.0 Analysis

The core loading and cycle depletion from the BRK1-19 fuel cycle design report (Reference 9) was used as the basis of the SLMCPR analysis. Figure 1 presents the core loading including the assembly type, the cycle the fuel was originally loaded, and the number of assemblies. The BRK1-19 core is made up of ATRIUM 10XM and ATRIUM-10 fuel. Analyses were performed [

] for the Brunswick power/flow map for MELLLA operation as shown in Figure 2. The BSP regions shown in the power/flow map are based on the methods discussed in Reference 10. The radial power distribution [

] is presented in Figure 3.

The operability assessment critical power correlation is used for the ATRIUM 10XM fuel while the SPCB critical power correlation (Reference 11) is used for the ATRIUM-10 fuel.

The fuel- and plant-related uncertainties used in the BRK1-19 SLMCPR analysis are presented in Table 1. The radial and nodal power uncertainty used in the analysis include the effects of up to 40% of the TIP channels out-of-service, up to 50% of the LPRMs out-of-service, and a 2500 effective full power hour (EFPH) LPRM calibration interval.

The BRK1-19 SLMCPR analysis supports a TLO SLMCPR of 1.07 and an SLO SLMCPR of 1.09. Table 2 presents a summary of the analysis results including the SLMCPR and the percentage of rods expected to experience boiling transition. The percentages of the total number of fuel rods predicted to experience boiling transition in the overall Monte Carlo statistical evaluation associated with each nuclear fuel type are presented in Table 3. The results are for the [

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### 4.0 Discussion of Results

Results from Reference 7 based on the currently approved ACE/TRIUM 10XM critical power correlation (Reference 4) are presented in Table 4. They are based on the same BRK1-19 design step-through and most of the same fuel- and plant-related uncertainties. The one exception is a slightly higher additive constant uncertainty associated with the currently approved correlation for the ATRIUM 10XM fuel – [

]. A comparison of results shows

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a decrease in the number of rods expected to experience boiling transition in both TLO and SLO with the use of the operability assessment correlation. The same SLMCPR limits are supported with both the currently approved ACE correlation (Reference 4) and the operability assessment correlation.

## 5.0 References

1. ANP-10307PA Revision 0, *AREVA MCPR Safety Limit Methodology for Boiling Water Reactors*, AREVA NP, June 2011.
2. ANF-524(P)(A) Revision 2 and Supplements 1 and 2, *ANF Critical Power Methodology for Boiling Water Reactors*, Advanced Nuclear Fuels Corporation, November 1990.
3. ANP-10249PA Revision 1, *ACE/ATRIUM-10 Critical Power Correlation*, AREVA NP, September 2009.
4. ANP-10298PA Revision 0, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2010.
5. BAW-10247PA Revision 0, *Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors*, AREVA NP, February 2008.
6. EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2*, Siemens Power Corporation, October 1999.
7. 51-9175814-001, "Brunswick Unit 1 Cycle 19 SLMCPR Analysis With SAFLIM3D Methodology (Proprietary Version)," AREVA NP, July 2012.
8. ANP-3086(P), *Brunswick Unit 1 and Unit 2 SLMCPR Operability Assessment Critical Power Correlation for ATRIUM 10XM Fuel - Improved K-factor Model*, AREVA NP, February 2012.
9. ANP-3005(P) Revision 0, *Brunswick Unit 1 Cycle 19 Fuel Cycle Design*, AREVA NP, June 2011.
10. 0G02-0119-260, *Backup Stability Protection (BSP) for Inoperable Option III*, GE Nuclear Energy, July 27, 2002.
11. EMF-2209(P)(A) Revision 3, *SPCB Critical Power Correlation*, AREVA NP, September 2009.
12. EMF-2493(P), *MICROBURN-B2 Based Impact of Failed/Bypassed LPRMs and TIPs, Extended LPRM Calibration Interval, and Single Loop Operation on Measured Radial Bundle Power Uncertainty*, AREVA NP, December 2000.
13. NEDO-20340, *Process Computer Performance Evaluation Accuracy*, General Electric, June 1974.
14. NEDO-10958-A, *General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application*, General Electric, January 1977.
15. NEDO-24344, *Brunswick Steam Electric Plant Units 1 and 2 Single-Loop Operation*, General Electric, September 1981.
16. Letter, H.D. Curet (AREVA) to H.J. Richings (NRC), "POWERPLEX Core Monitoring: Failed or Bypassed Instrumentation and Extended Calibration," HDC:96:012, May 6, 1996 (38-9043714-000).
17. 0B21-1305 Revision 1, "Core Monitoring LPRM Uncertainty and Sensitivity Decay," Progress Energy, March 2009 (NRC Accession Number ML092370285).

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Table 1 Fuel- and Plant-Related Uncertainties for BRK1-19 SLMCPR Analyses		
Parameter	Uncertainty	Reference
<i>Fuel-Related Uncertainties</i>		
[		
		]
<i>Plant-Related Uncertainties</i>		
Feedwater flow rate	1.8% <sup>†</sup>	14
Feedwater temperature	0.8% <sup>†</sup>	14
Core pressure	0.8% <sup>†, §</sup>	13
Total core flow rate		
TLO	2.5%	14
SLO	6.0%	15

\* [ ]

† Values from Reference 12 are a result of the application of the methodology discussed in Reference 16 to the base uncertainties presented in Reference 6. The uncertainties presented support operation with up to 50% of LPRMs out-of-service, up to 40% of the TIP channels out-of-service, and a 2500 EFPH LPRM calibration interval. The bases of these values include a core monitoring LPRM detector uncertainty of 4.3% from Reference 17.

‡ Referenced plant uncertainties were rounded up to the nearest 0.1% before use.

§ The core pressure uncertainty is taken in Reference 13 to be a more conservative value than accepted in Reference 14; therefore, the more conservative value is used.

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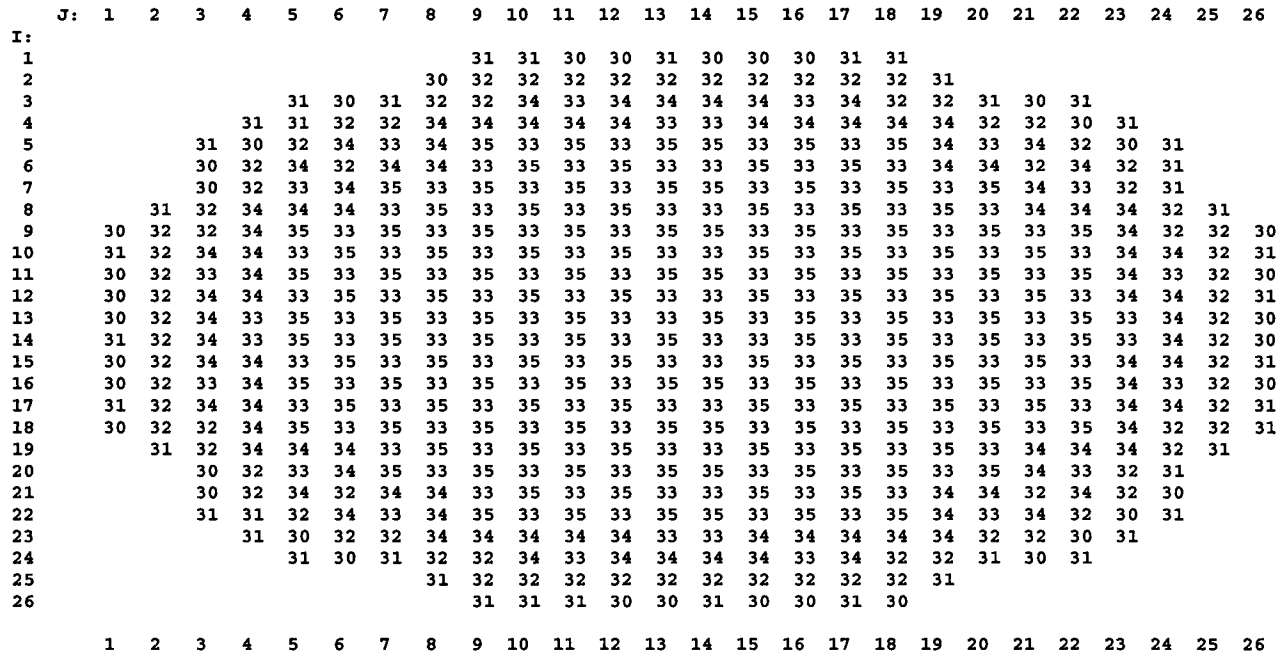
<b>Table 2 BRK1-19 Results Summary for SLMCPR Analysis (Operability Assessment CPR Correlation for ATRIUM 10XM)</b>	
SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.07	0.051
SLO – 1.09	0.053

<b>Table 3 Contribution of Total Predicted Rods in BT by Nuclear Fuel Type</b>				
Nuclear Fuel Type	Fuel Design	Burnup Status	Contribution of Total Rods Predicted To Be in BT (%)	
			TLO	SLO
30	ATRIUM-10	Twice burned	[	
31	ATRIUM-10	Twice burned		
32	ATRIUM-10	Once burned		
33	ATRIUM-10	Once burned		
34	ATRIUM 10XM	Fresh		
35	ATRIUM 10XM	Fresh		]

<b>Table 4 BRK1-19 Results Summary for SLMCPR Analysis (Reference 4 ACE/ATRIUM 10XM CPR Correlation)</b>	
SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.07	0.073
SLO – 1.09	0.083



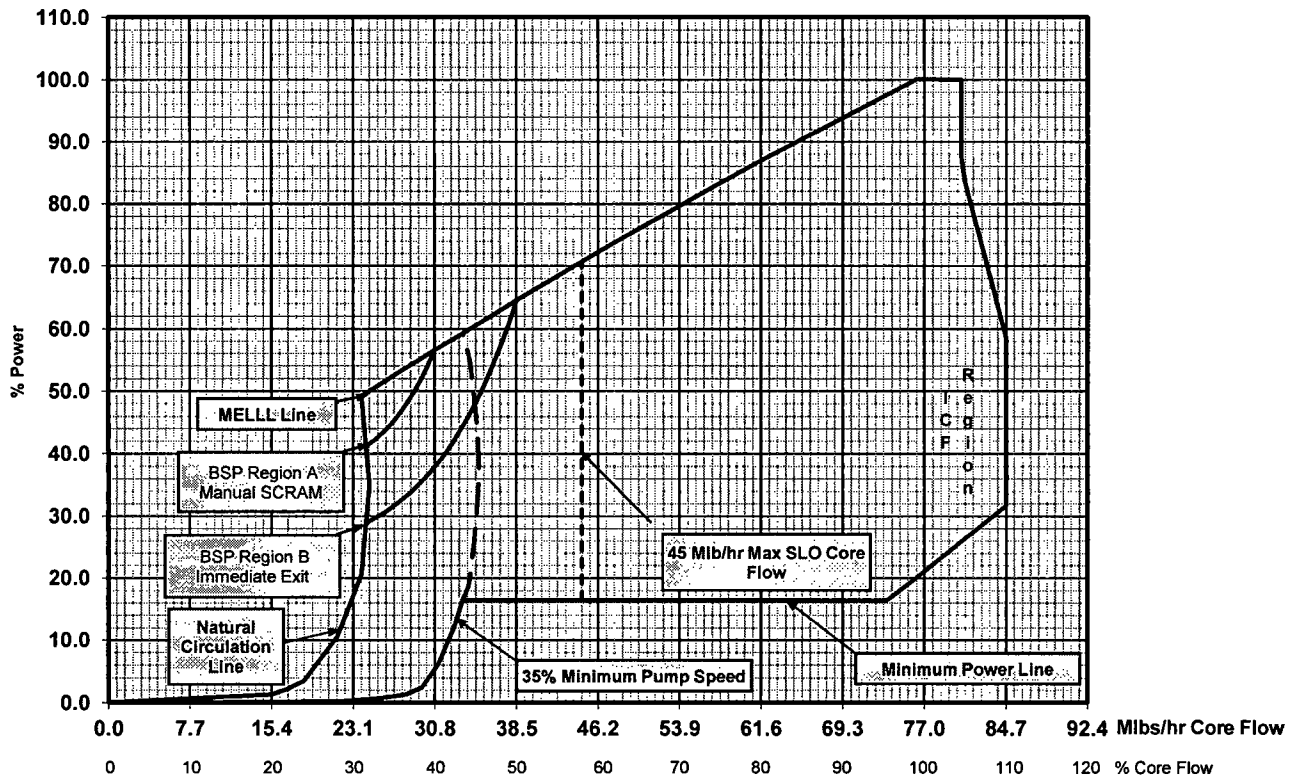
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Nuclear Fuel Type	Fuel Description	Cycle Loaded	Number of Assemblies
30	ATRIUM-10	17	38
31	ATRIUM-10	17	46
32	ATRIUM-10	18	80
33	ATRIUM-10	18	162
34	ATRIUM 10XM	19	96
35	ATRIUM 10XM	19	138

Figure 1 Brunswick Unit 1 Cycle 19  
Core Loading Map

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**Figure 2 Brunswick Unit 1  
Power/Flow Map With Nominal  
Feedwater Temperature BSP Regions**

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	J: 1	2	3	4	5	6	7	8	9	10	11	12	13
I:													
1									0.325	0.376	0.416	0.430	0.437
2								0.416	0.617	0.712	0.757	0.786	0.801
3					0.279	0.384	0.517	0.735	0.874	1.103	0.943	1.163	1.167
4				0.311	0.484	0.692	0.827	1.117	1.227	1.279	1.301	1.302	1.076
5			0.271	0.486	0.765	1.040	0.965	1.277	1.329	1.121	1.361	1.116	1.325
6			0.368	0.693	1.042	1.043	1.298	1.353	1.141	1.369	1.135	1.330	1.060
7			0.512	0.829	0.975	1.298	1.351	1.147	1.380	1.147	1.358	1.069	1.028
8		0.425	0.733	1.114	1.275	1.350	1.143	1.373	1.145	1.359	1.107	1.276	0.848
9	0.322	0.616	0.872	1.221	1.323	1.142	1.384	1.153	1.344	1.099	1.299	1.050	1.240
10	0.383	0.710	1.096	1.269	1.122	1.362	1.144	1.336	1.052	1.245	1.041	1.265	1.053
11	0.398	0.747	0.935	1.290	1.346	1.130	1.354	1.073	0.984	0.807	1.199	1.033	1.267
12	0.424	0.776	1.153	1.294	1.118	1.351	1.123	1.263	0.811	0.945	0.980	1.228	1.024
13	0.426	0.794	1.159	1.078	1.343	1.127	1.322	1.049	1.190	0.966	1.212	1.014	1.017
14	0.435	0.792	1.159	1.078	1.343	1.127	1.321	1.050	1.190	0.968	1.215	1.025	1.244
15	0.425	0.776	1.153	1.293	1.117	1.349	1.121	1.261	0.810	0.946	0.984	1.238	1.030
16	0.396	0.745	0.934	1.288	1.344	1.128	1.351	1.071	0.983	0.816	1.201	1.038	1.267
17	0.374	0.708	1.094	1.267	1.119	1.358	1.132	1.332	1.054	1.243	1.040	1.263	1.051
18	0.321	0.614	0.870	1.218	1.320	1.139	1.380	1.148	1.339	1.092	1.295	1.054	1.236
19		0.425	0.733	1.112	1.271	1.346	1.143	1.368	1.141	1.353	1.104	1.270	0.845
20			0.511	0.826	0.964	1.294	1.346	1.142	1.373	1.140	1.352	1.061	1.023
21			0.380	0.690	1.038	1.042	1.293	1.347	1.131	1.362	1.130	1.324	1.056
22			0.266	0.481	0.762	1.036	0.961	1.272	1.323	1.115	1.355	1.110	1.319
23				0.304	0.483	0.689	0.820	1.111	1.221	1.274	1.296	1.296	1.074
24					0.269	0.379	0.500	0.730	0.869	1.099	0.939	1.159	1.164
25								0.409	0.614	0.709	0.755	0.783	0.800
26									0.322	0.376	0.409	0.428	0.442
	1	2	3	4	5	6	7	8	9	10	11	12	13
	J:14	15	16	17	18	19	20	21	22	23	24	25	26
I:													
1	0.439	0.433	0.411	0.380	0.329								
2	0.799	0.783	0.754	0.711	0.616	0.429							
3	1.166	1.162	0.940	1.103	0.874	0.735	0.518	0.392	0.273				
4	1.075	1.301	1.301	1.280	1.228	1.118	0.828	0.693	0.484	0.308			
5	1.325	1.116	1.362	1.120	1.332	1.280	0.967	1.041	0.764	0.484	0.270		
6	1.060	1.331	1.135	1.372	1.142	1.356	1.301	1.044	1.040	0.691	0.380		
7	1.028	1.070	1.362	1.142	1.384	1.148	1.354	1.300	0.964	0.825	0.517		
8	0.848	1.279	1.114	1.364	1.148	1.378	1.146	1.353	1.276	1.113	0.731	0.422	
9	1.241	1.052	1.304	1.105	1.350	1.154	1.389	1.142	1.327	1.222	0.869	0.612	0.323
10	1.054	1.270	1.044	1.252	1.050	1.342	1.145	1.369	1.123	1.273	1.097	0.706	0.376
11	1.271	1.037	1.207	0.813	0.989	1.076	1.361	1.133	1.353	1.295	0.936	0.750	0.405
12	1.031	1.243	0.986	0.951	0.814	1.271	1.125	1.360	1.121	1.300	1.158	0.779	0.440
13	1.245	1.025	1.219	0.970	1.197	1.054	1.331	1.130	1.352	1.081	1.165	0.796	0.435
14	1.015	1.017	1.216	0.969	1.196	1.053	1.331	1.130	1.352	1.082	1.165	0.797	0.435
15	1.022	1.229	0.979	0.948	0.812	1.269	1.125	1.359	1.121	1.300	1.159	0.779	0.439
16	1.265	1.032	1.200	0.814	0.986	1.073	1.359	1.132	1.352	1.295	0.936	0.751	0.405
17	1.049	1.264	1.038	1.247	1.054	1.339	1.136	1.367	1.122	1.273	1.097	0.706	0.376
18	1.236	1.047	1.298	1.093	1.345	1.152	1.387	1.141	1.326	1.222	0.870	0.613	0.321
19	0.843	1.272	1.105	1.358	1.144	1.375	1.145	1.354	1.276	1.114	0.731	0.421	
20	1.024	1.065	1.356	1.136	1.380	1.145	1.354	1.301	0.964	0.826	0.512		
21	1.055	1.326	1.128	1.368	1.140	1.355	1.302	1.044	1.042	0.692	0.384		
22	1.320	1.111	1.358	1.116	1.331	1.281	0.976	1.043	0.765	0.483	0.272		
23	1.072	1.298	1.298	1.278	1.228	1.119	0.828	0.693	0.487	0.308			
24	1.164	1.160	0.937	1.103	0.874	0.734	0.518	0.387	0.271				
25	0.797	0.782	0.754	0.711	0.617	0.429							
26	0.439	0.433	0.418	0.380	0.332								
	14	15	16	17	18	19	20	21	22	23	24	25	26

Figure 3 Radial Power Distribution for  
Brunswick Unit 1 Cycle 19  
SLMCPR [ ]  
With Operability Assessment CPR Correlation